Restoration of mixed-species forest by gap technique in Sanjiang Plain

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Abstract Many methods of restoration and rebuilding of forestry ecosystem were used, because the function of the secondary broad-leaved forests declined. One of these methods was the artificial regeneration carried out with gap technique in the forest. The results showed that the communities had been getting to Korean pine forests mixed with broad-leaved trees and the speed of development was much faster than before.
Key words: Secondary broad-leaved forest, Gap, Restoration

Introduction

Korean pine (*Pinus koraiensis* Sieb. et Zucc.) forest mixed with broad-leaved trees is a climax vegetation type in Northeast China (Wang 1994; Nie 1995; Zhou 1994). Because the forest dominated by *Pinus koraiensis* that has very high ecological and economic value (Wang 1994; Nie 1995; Zhou 1994), it is one of the most complicated plant community types in Northeast Asia. This forest is very important for the maintenance of biodiversity and the conservation of water and soil in the regional area (Liu 1957; Zhang 1957; Zhang 1986; JiLin 1990; Wang 1994; Nie 1995). Since more than 100 years ago, a lot of research works had been done on the forest, including floristic investigation and natural plant resources in the forest, geographical distribution and community history of the forest, biological and ecological characteristics of the trees, and structure and functions of the forest ecosystem (Wang 1994). However, the relationship between Korean pine regeneration and light environment was the key research topic.

In 1950s scientists thought that Korean pine was a shade-tolerant species, its seedlings couldn't grow in clear-cutted sites (San 1951; Liu 1957). The reason for this was that direct sun light caused soil temperature increasing so high temperature that the seedlings were withered consequently, nature regeneration should be main form, and artificial reforestation should be assisting form for Korean pine regeneration (San 1951). However, a lot of research works indicated that Korean pine could live in full-light environment. Moreover, its seedlings grew faster and better in selected-cut sites created by strip felling pattern (He 1958).

In 1960s, the results showed that growth rate of diameter and tree height of Korean pine reforestation stands were far higher than that of natural stands (Cheng 1963; Wang 1965). However, the restoration of Korean pine forests by artificial reforestation form caused other problems, such as branching in too early stage (Liu 1965; Li 1986). Therefore, artificial reforestation for Korean pine forest restoration was not a good way.

Due to the difficulties of natural regeneration and disadvantages of artificial reforestation of Korean pine, forest scientists sought other ways for restoring mixed-species stands dominated by Korean pine. One of those ways was promoting regeneration of Korean pine by broad-leaved trees based on the biological and ecological characteristics of the tree (Wang 1958; Wang 1994). The artificial regeneration of Korean pine was carried out under the canopies of broad-leaved trees and the results indicated that less than 0.6 of the crown density of broad-leaved trees was suitable for artificial regeneration of Korean pine. By this way, the secondary broad-leaved tree mixed forests could be transformed into mixed-species stands dominated by Korean pine (Wang 1986; Zhang 1986; Wang 1987; JiLin 1990; Wang 1994; Nie 1995). So that, the patch artificial regeneration technique of Korean pine in secondary broad-leaved forests is employed in the restoration of Korean pine forests mixed with broad-leaved trees.

Materials and methods

Site description

Xianfeng Forest Farm is located in Sanjiang Plain(45° 58 ′ N, 129 °26 ′ E) with continental monsoon cli-

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mate, climatic data around the area indicates that a mean annual precipitation is 650mm, annual average temperature is 3.0℃. This work was carried out in the secondary forests, which occupied the disturbed sites that originally were covered by Korean pine forest mixed with broad-leaved trees.

Sampling

In 1991, the coniferous seedlings of several species were planted in gaps of mixed broad-leaved stands that were created by various factors. After four years, the reforestation sites were investigated by random sampling method, the gaps with different areas were selected and reforested seedlings in the gaps were measured. Investigation factors included growth rate, ground diameter of the seedlings in gaps and under the canopies of broad-leaved trees. All the data were processed on computer.

Results and discussion

Gap areas affecting on the *Pinus koraiensis*

The microclimate of gaps is an intermediate type between the microclimates of forests and open air. Light intensity of gaps changes with the area of gap area. As the diameter of gaps is less 1~1.5 times of tree height, light intensity increases rapidly and with further increase of gap area, then it increases slowly (Mayer 1976).

The ground diameter and the height are the highest in the gap which area is about 15 m^2, the gap's diameter is about 4.37 m (Table 1, Fig.1, 2).

The height of surrounding trees is approximately 12m; the gap's diameter is equal to one-third tree height. Its intensity of light is obviously different from that under the forest canopy. The situation in the 15 m^2 gap fits to the young pine trees that need not strong but proper light according to their shade tolerant characteristics.

But when the gap area becomes smaller, the tree height and the ground diameter show a declining tendency, that because the situation under the gap is similar to that under the forest canopy. Although the Korean pine is a shade-tolerant species, its tolerance is limited.

Why do the growth targets of Korean pine show a declining tendency when the gap become larger? Firstly, the situation in the gap changes clearly, for example, the wind picks up, the air temperature and the surface temperature rise and the humidity drops. These factors maybe affect the forest growth. Secondly, the site conditions may be differing from each other, some poor site condition made the seedling growth slowly, that is why these places are easier to become gaps than the others.

Table 1. Gap area and the growth targets of *Pinus koraiensis*

No.	Gap area /m^2	Average ground diameter /cm	Average height /m
1	72.10	0.657	0.282
2	10.00	0.758	0.298
3	81.60	0.668	0.227
4	22.50	0.747	0.342
5	4.08	0.691	0.248
6	3.25	0.786	0.259
7	13.65	0.853	0.380
8	2.53	0.755	0.264
9	0.38	0.740	0.252
10	39.9	0.815	0.332
11	11.70	0.774	0.341
12	36.48	0.779	0.277
13	6.30	0.771	0.314
14	8.34	0.800	0.327
15	20.52	0.761	0.305
16	54.40	0.744	0.317
17	14.85	0.832	0.295

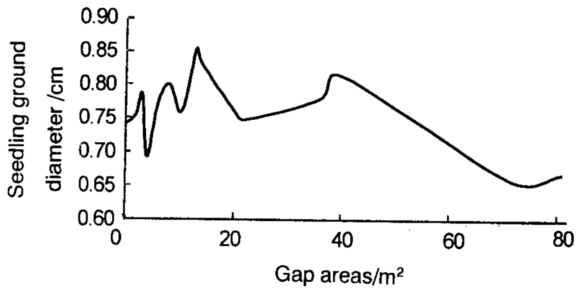

Fig. 1. Change of different ground diameters and different gap areas

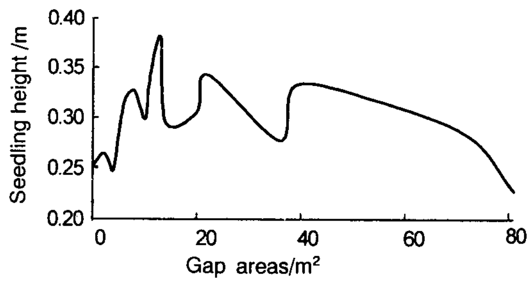

Fig. 2. Change of different heights and different gap areas

The proper gap area is important not only for Korean pine seedling growth, but also for the seedling avoiding branch and broken (Jia 1965; Li 1965; Liu 1965; Yao 1986; Wang 1987; Zhan 1986; Ge 1993; Wang 1994). Therefore, the gap area is key factor for selecting the sites and the reforestation of Korean

pine seedlings.

Comparison of the growth targets of *Pinus koraiensis* in the gaps and under the forest canopies

All ground diameters in the gaps are larger than that under the forest canopies (Table 2, Fig.3). Identically, all heights of seedlings in the gaps are higher than that under the forest seedlings (Fig.4).

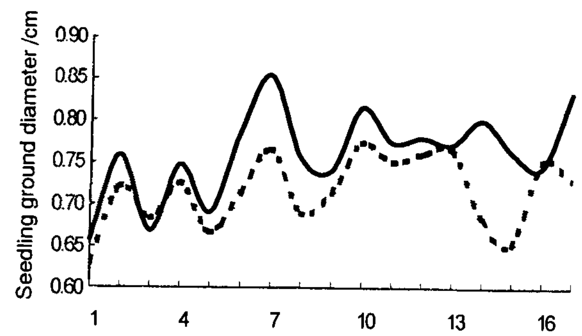

Fig. 3. Comparison of the ground diameter in the gaps and under the forest canopies

—Seedling ground diameter in the gap

----Seedling ground diameter under the forest canopy

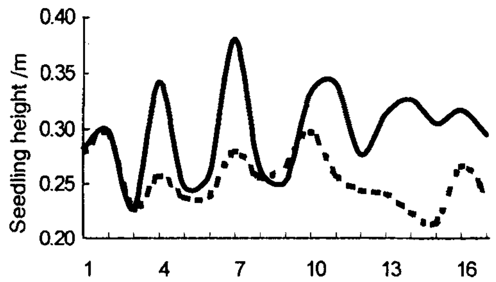

Fig. 4. Comparison of the height in the gaps and under the forest canopies

—Seedling height in the gap

----Seedling height under the forest canopy

The test results show that the ground diameters of Korean pine seedlings have remarkable difference among those in the gap and under the forest canopy (Table 3). The heights of the pine seedlings have extremely remarkable difference between them (Table 4). Because of the difference of microclimate in gaps and under forest canopies, when gap effects were created by broad-leaved trees around gaps, the broad-leaved trees influenced the light environment over Korean pine seedlings. In this period, height growth of seedlings was promoted and diameter growth was inhibited (Ge 1993). In this way, we can keep a proper ratio of height and diameter.

Moreover, early branching of Korean pine is avoided. However, the Korean pine grows bigger and needs more light, the over stories of broad-leaved trees should be cutted and proper light environment could be maintained according to the change of the seedling need for light in its various developing stages. By this treatment, we can create a mixed stand dominated by Korean pine and associated by broad-leaved trees.

Table 2. Growth targets of *Pinus koraiensis* under the forest canopies

No.	Average ground diameter /cm	Average height /m
1′	0.629	0.278
2′	0.721	0.295
3′	0.683	0.227
4′	0.725	0.257
5′	0.667	0.238
6′	0.713	0.239
7′	0.765	0.279
8′	0.690	0.256
9′	0.714	0.267
10′	0.773	0.297
11′	0.750	0.258
12′	0.760	0.244
13′	0.764	0.241
14′	0.682	0.224
15′	0.653	0.215
16′	0.750	0.266
17′	0.729	0.240

Notes: 1′~17′ stands for the control plot number which correspond with the same number in the gap

Table 3. Variance analysis on the ground diameter of *Pinus koraiensis*

Source of variation	Sum of squares of deviation	Freedom	Mean square deviation	F	F_{α}
Among the groups	0.017	1	0.0170	7.39	$F_{(0.05)}(1, 32)=4.15$
In the groups	0.074	32	0.0023		$F_{(0.01)}(1, 32)=7.50$
Total	0.091	33			

Table 4. Variance analysis on the height of *Pinus koraiensis*

Source of variation	Sum of squares of deviation	Freedom	Mean square deviation	F	F_{α}
Among the groups	0.019	1	0.0190	16	$F_{(0.05)}(1, 32)=4.15$
In the groups	0.038	32	0.0011		$F_{(0.01)}(1, 32)=7.50$
Total	0.057	33			

Results of reforming the secondary broad-leaved forest

When the gap area is about 15 m^2, the Korean pine seedlings can grow well, and the seedlings in gaps grow better than those under the forest canopies, in the same time, broad-leaved trees grow faster than before. Before we opened up gaps, the broad-leaved tree volumes in every hectare grow 3.5 m^3 every year (Table 5). Since 1991, the volume has increased to 4.8 m^3 average. The broad-leaved trees around gaps not only are important components of the potential Korean pine forests mixed with broad-leaved trees, but also they create a proper environmental condition for the Korean pine seedlings. Therefore, during the restoration of the secondary forests, the productivity of broad-leaved trees gradually needs to be enhanced. The light environment of the broad-leaved trees mixed stands needs to be transformed by selective cutting over stories.

Table 5. Yield of the main species in the secondary forest

Species	1990		1995		Number of Korean pine in every hectare
	Diameter of breast height /cm	Volume /(m^3•hm^{-2})	Diameter of breast height /cm	Volume /(m^3•hm^{-2})	
Quercus mongolica	15.30	0.1017	15.82	0.1329	357
Acer mono	7.09	0.0157	9.63	0.0367	114
Tillia amurensis	9.20	0.0295	10.48	0.0472	104
Fraxinus mandshurica	11.28	0.0517	13.64	0.1070	100
Populus davidiana	9.13	0.0345	12.82	0.0832	61

Conclusions

Gaps existing in the secondary broad-leaved forest have proper light and nutrition states. During the process of restoration of secondary broad-leaved forests, in the early aged, the gap with a proper area is suitable for the Korean pine growth. However, gaps should be enlarged generally when Korean pine seedlings need more light as they grow up. The lower-productive trees should be cut for selective cutting, the conifer should grow faster, the species composition and forest stand structure should be improved. Finally, Korean pine forests mixed with broad-leaved trees should be formed.

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